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DYNAMIC EVALUATION OF EXPERIMENTAL INTEGRAL FUEL TANK SEALANTS

RESEARCH APPLICATIONS DIVISION
SYSTEMS RESEARCH LABORATORIES, INC.
2800 INDIAN RIPPLE ROAD
DAYTON, OHIO 45440

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This final report was submitted by Systems Research Laboratories, Inc. (SRL), 2800 Indian Ripple Road, Dayton, Ohio 45440, under Contract No. F33615-76-C-5253, Project Nos. 2421 and 7340, with the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio 45433. William F. Anspach, AFML/MBE, was the Air Force Materials Laboratory Project Engineer.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

William F. Anspach

WILLIAM F. ANSPACH
Project Engineer

FOR THE COMMANDER

J. M. Kelble
Chief
Nonmetallics Materials Division

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Research was performed to evaluate the sealant properties of elastomeric materials under simulated in-service conditions. Unique equipment has been designed and fabricated for the evaluation of a variety of joint configurations. The equipment consists primarily of a biaxial stress machine with programmable environmental exposure during evaluation. Variables include frequency and amplitude of the independently driven and recorded strains, temperature, pressure and fuel/fuel vapor exposure. Specimens can be strained torsionally and longitudinally during thermal and fuel fill cycles to simulate actual flight conditions.

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INTRODUCTION

Improvements in polymeric fuel tank sealants are continually being made in order to meet current and projected Air Force requirements. The need for new materials which will satisfy the more stringent conditions in present and future aircraft and the need to understand the behavior of sealed joints makes it highly desirable to develop procedures which enable materials to be evaluated under simulated in-service conditions. Equipment developed under previous Air Force contracts (F33615-70-C-1422 and F33615-72-C-1594) demonstrated the feasibility of dynamic evaluations and clearly showed the need for the development of a more sophisticated evaluation system which would allow better control of test parameters.

The objectives of the work described in this report are as follows:

- Design and build a machine for dynamically evaluating fuel tank sealants under simulated flight conditions.
- Design test specimens in continuous fillet, corner, and channel configurations for evaluation of sealants.
- Following development of the system, evaluate sealant samples supplied by the Air Force.

Under the present contract (F33615-76-C-5253), a system has been developed which is capable of simulating a complete flight including loading, take off, cruise and high speed flight, landing, and shutdown. The system is capable of repeating this flight simulation with a high degree of accuracy. Feasibility of the system for evaluating sealants has been proven by demonstration runs with and without fuel. Fully automatic evaluations will begin as soon as the GFE leak detection equipment has been installed; in the meantime, evaluations will continue with the present system.

SECTION II

PHASE I: DEVELOPMENT OF DYNAMIC EVALUATION EQUIPMENT

The apparatus for dynamic evaluation of elastomeric fuel tank sealants developed by SRL under the present contract is shown in Figs. 1-5. Figure 1 is a photograph of the system showing the testing chamber with associated equipment, the control console, and the fuel storage tanks. Figures 2-4 are assembly drawings of the chamber, and Fig. 5 is a block diagram of the electrical, gas, vacuum, and cooling connections. Figure 6 shows a test specimen for a continuous fillet. This specimen consists of a cup and a disk, the two being joined by sealant material around the bottom of the cup.

The system applies independent torsional and joint-opening forces to the elastomer joint. The disk represents the skin of the tank, and the cup represents the interior support structure to which the skin is bonded. The disk separates the upper chamber (which simulates the interior of the fuel tank) of the test machine from the lower chamber (which simulates the outside atmosphere). The exterior skin is heated to simulate frictional heat during flight and is subjected to temperature and pressure changes which are comparable to those encountered during normal flight and landing.

The fuel tank must be filled prior to the simulated flight and empty or nearly empty at the time of landing, with the pressure within the tank simulating that in a real aircraft.

The first detailed design of this system was based upon the design parameters and conceptual drawing submitted by SRL in Unsolicited Proposal No. 18149. The design was reviewed at a meeting on 21 May 1976 with Messrs. William Anspach (Materials Engineer, MBE), Jerome Kelble (Chief, Nonmetallic Materials Division), Roger Headrick (Technical Manager for Elastomers), Jerry Sieron (Senior Materials Engineer, MBE), and Phil House (Materials Engineer, Systems Support). The design was approved for fabrication with one exception--the SRL design utilized a T.C. vacuum gauge which shut down the system at the first indication of a leak, and AFML personnel indicated that they would prefer that the system note a leak but not shut down until the leak rate

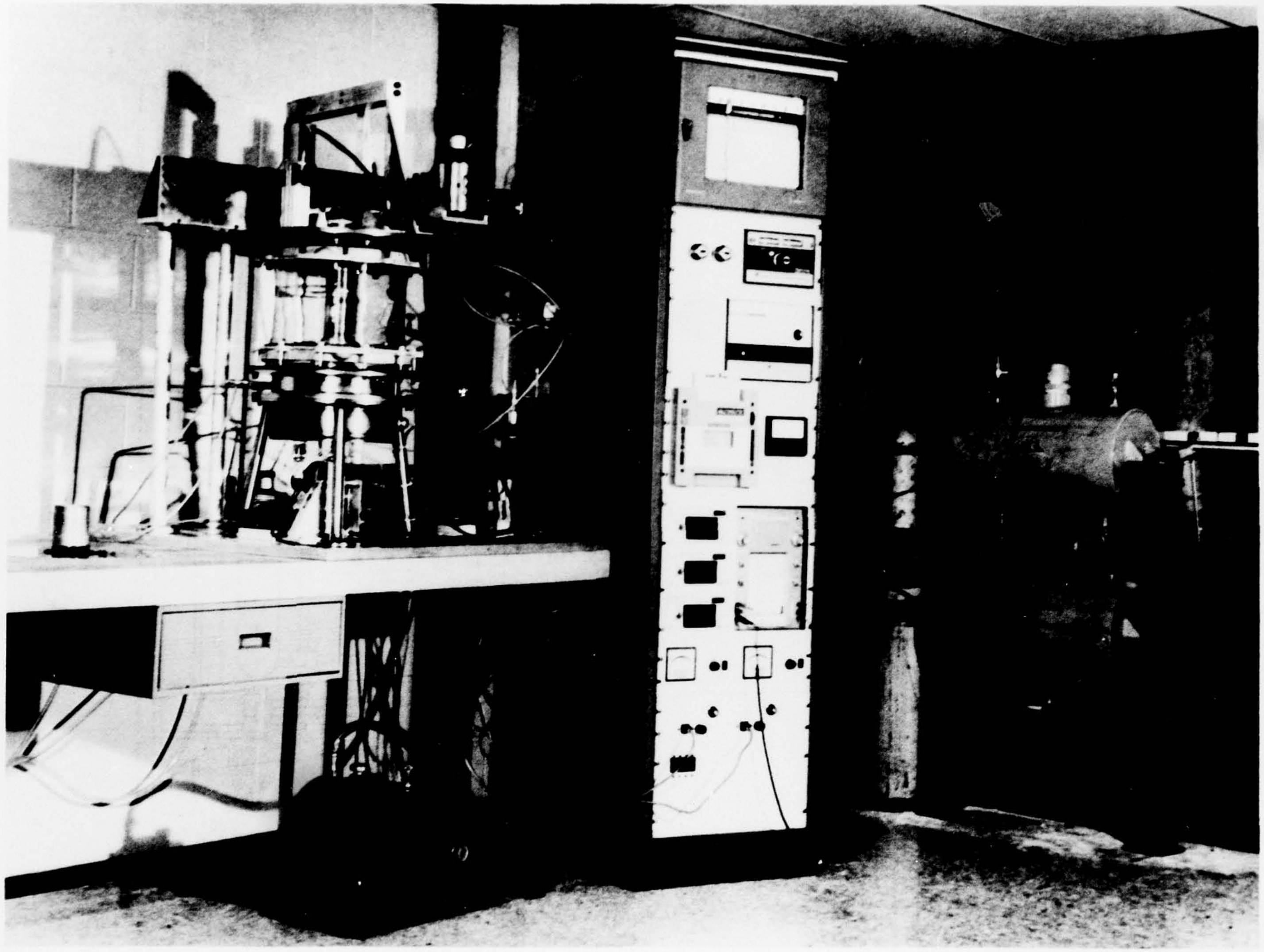

Figure 1. Dynamic Elastomeric Sealant Evaluator

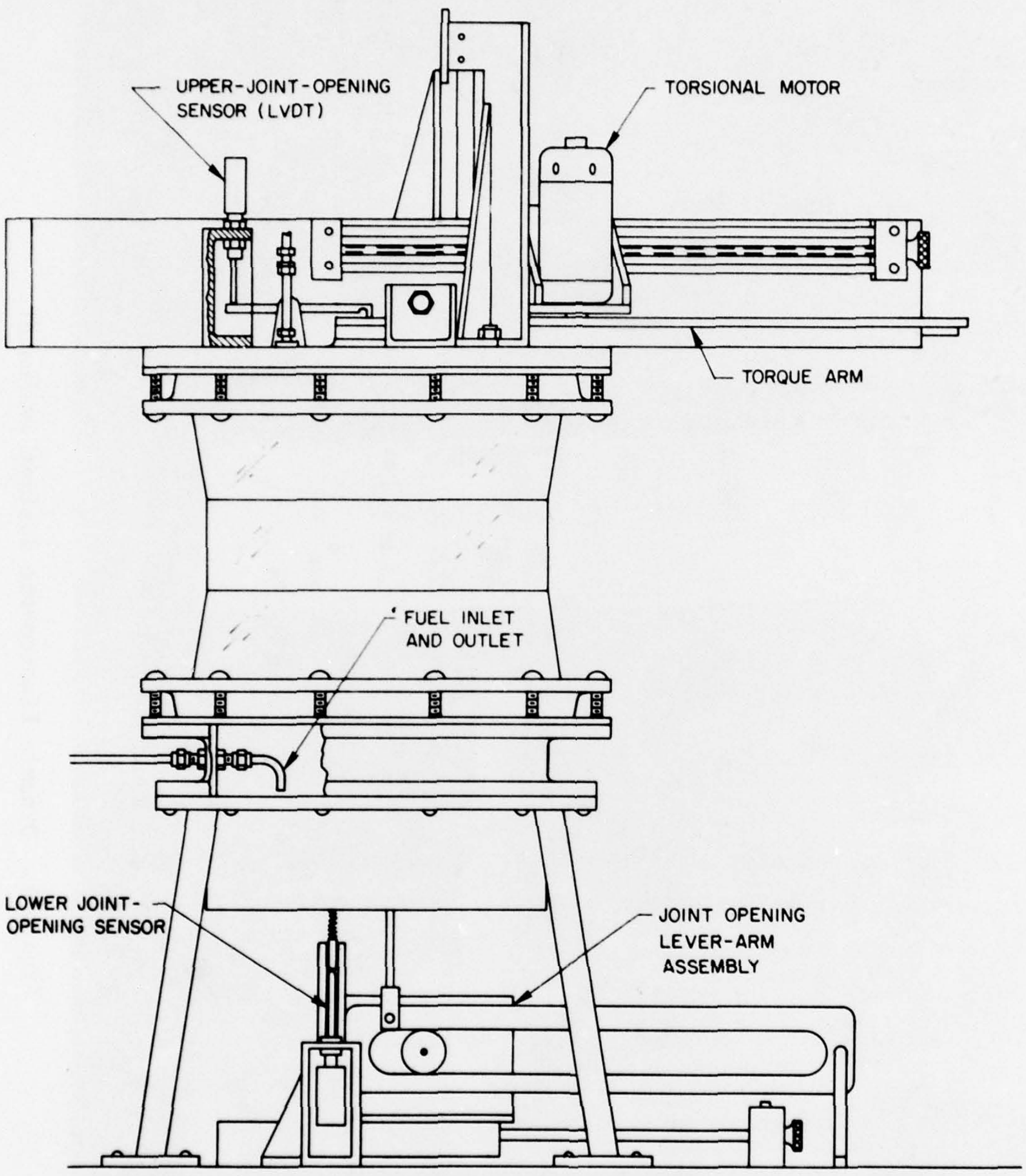

Figure 2. Front View of Dynamic Fuel Tank Sealant Evaluator

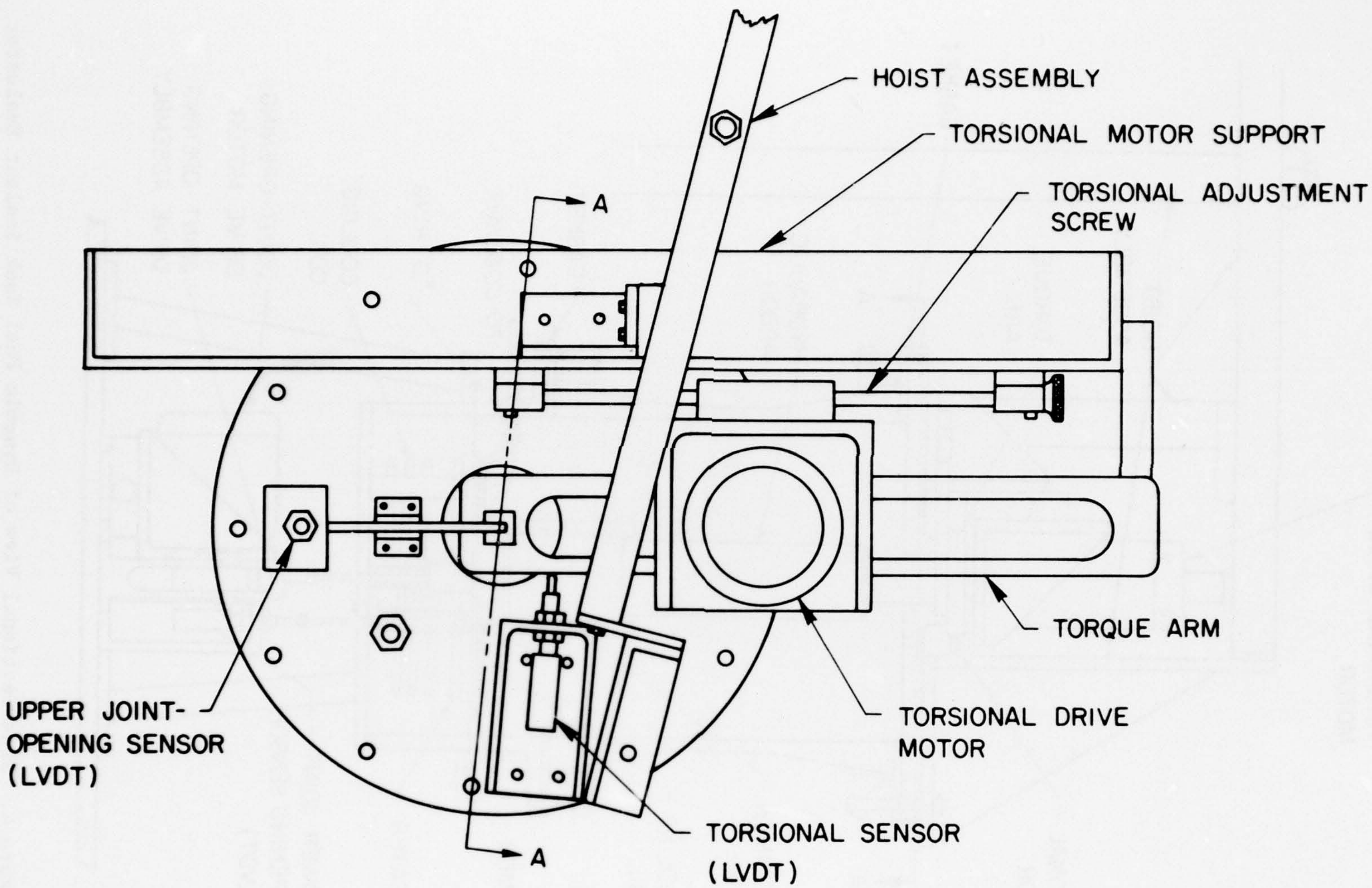

Figure 3. Top View of Dynamic Fuel Tank Sealant Evaluator

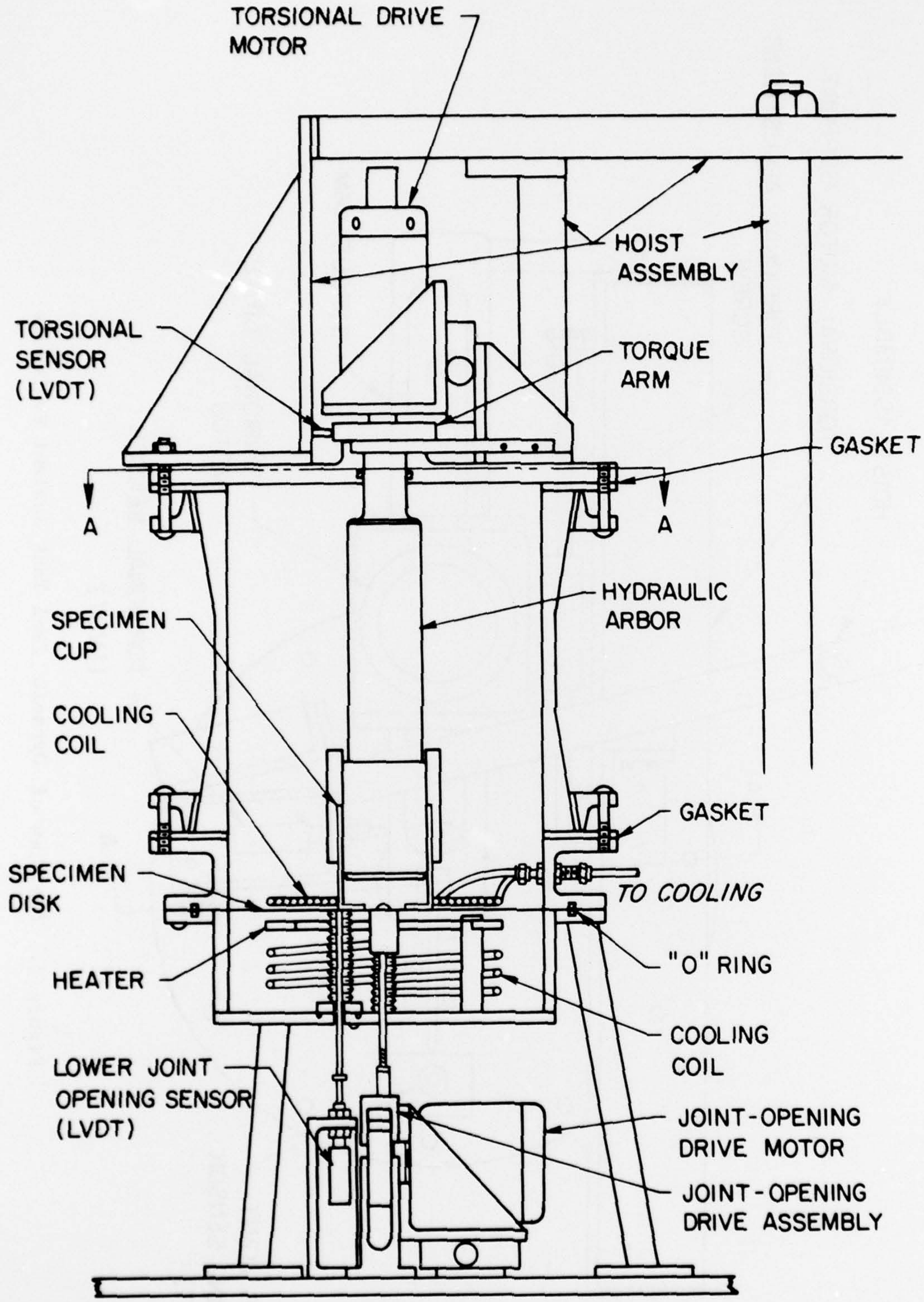

Figure 4. Side Sectional View of Dynamic Fuel Tank Sealant Evaluator

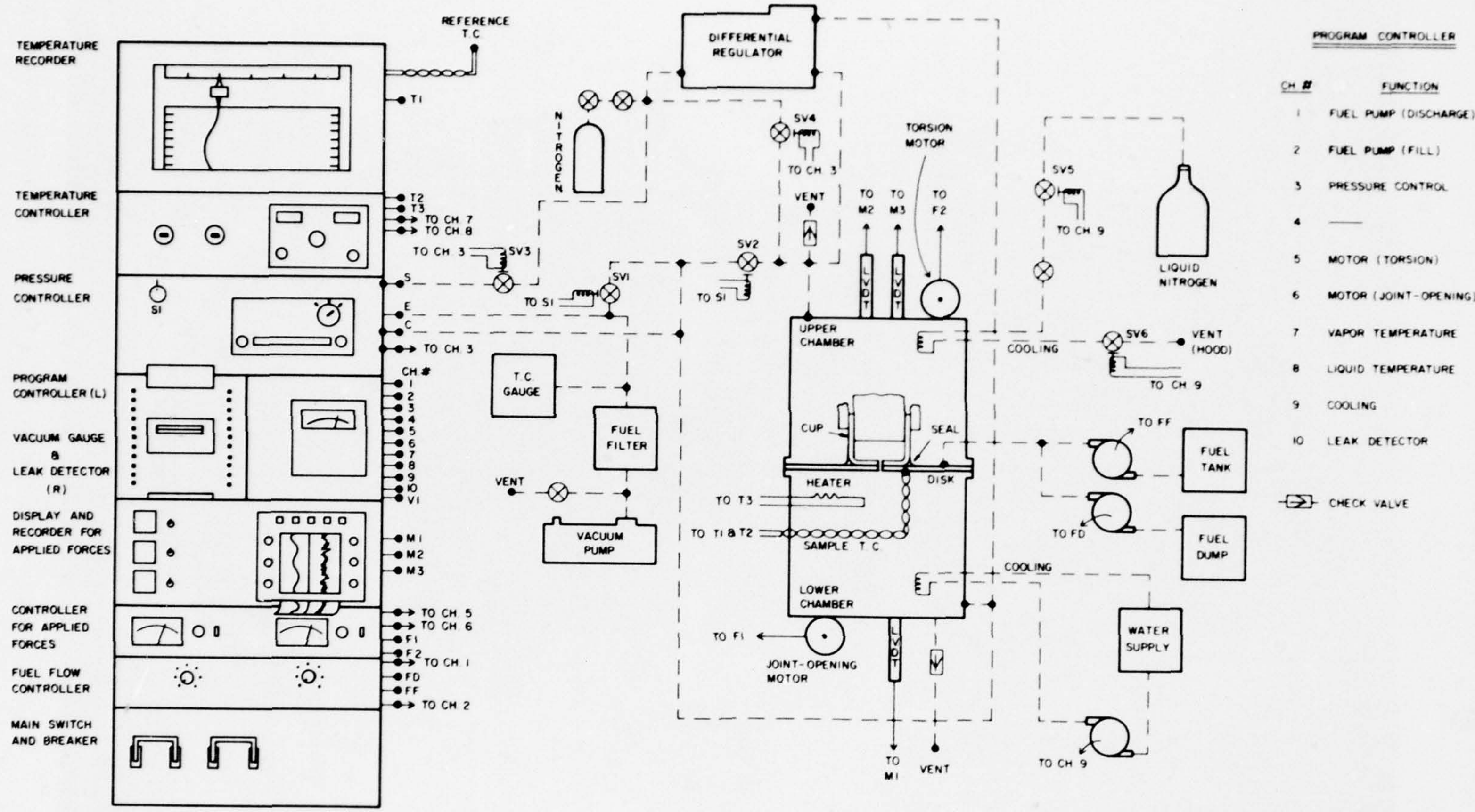

Figure 5. Block Diagram of Dynamic Fuel Tank Sealant Evaluator

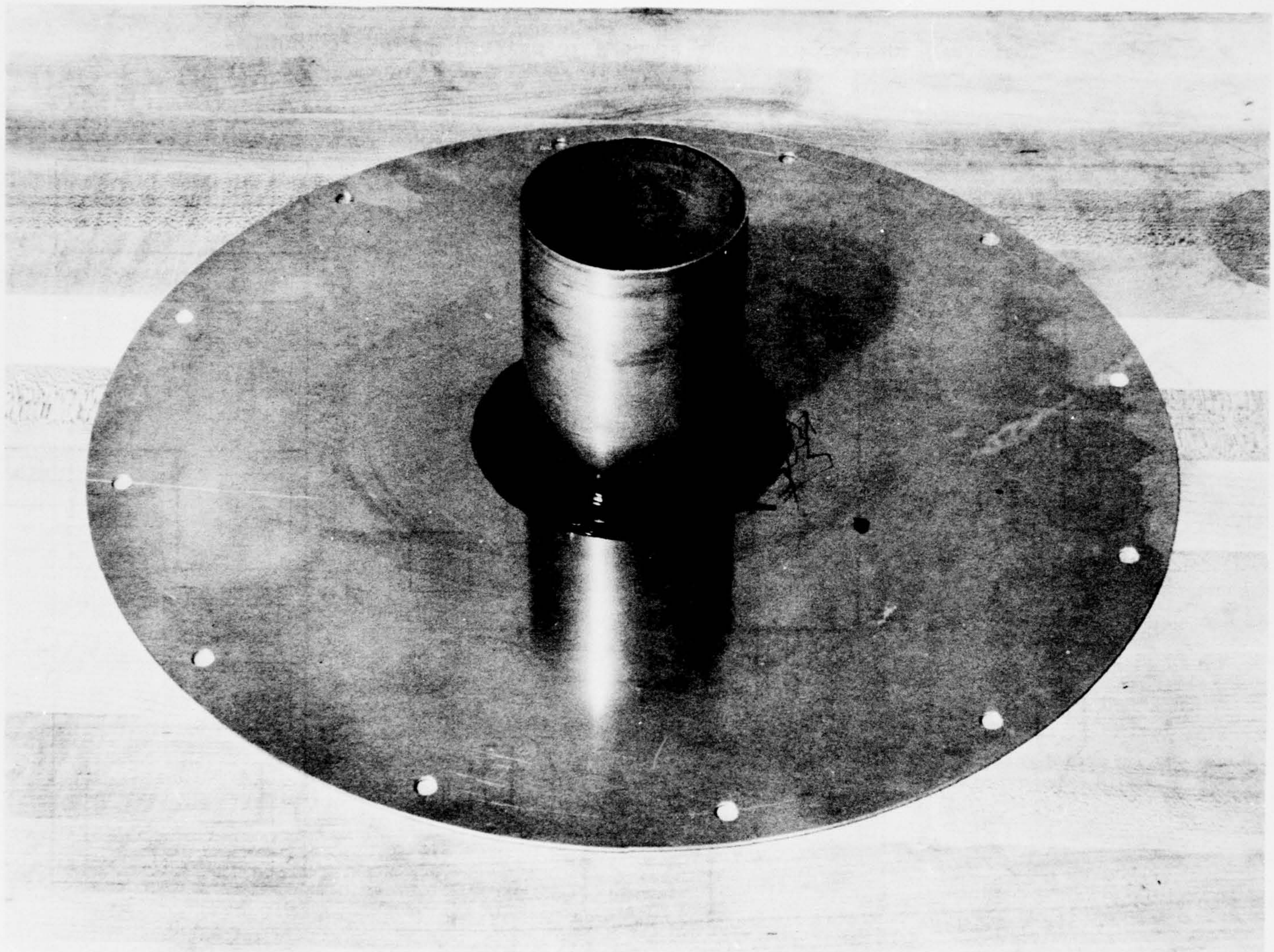

Figure 6. Continuous Fillet Evaluation Specimen

reached a preset value. A dual set point hydrocarbon detector has been selected to meet these requirements and will be furnished by the Air Force. Until this system becomes available, a single set point system will be used.

The evaluation sequence is controlled by a moving program card in a Program Card Controller made by Automatic Timing and Controls, Inc. (see Figs. 1 and 5). The card has 24 independent channels available, nine of which are used in the evaluation. On each channel a microswitch in the open position rests on a ridge which is machined away in regions corresponding to times during which the switch should be closed.

The chamber in which the evaluation takes place is separated into upper and lower sections by the disk part of the test specimen (see Figs. 1, 4, and 5). The lower chamber is made of stainless steel. The upper chamber has a base and top made from stainless steel and a central portion which is a 12-in.-diameter Pyrex cylinder. The transparent cylinder permits observation of the specimen during evaluation. Gaskets made from buna-N rubber are inserted on the top and bottom of the Pyrex cylinder.

The description of the system below assumes that a continuous fillet joint is being evaluated. The system can also be used with corner and channel configurations; preliminary designs have been completed for such configurations.

The disk specimen is held rigidly and the cup specimen is clamped by a hydraulically expanding arbor (Positrol, Inc.) which locks the cup on the i.d. (the cup has a 3-in. i.d. with a 0.050-in. wall). An external sleeve confines the cup so that repeated cycling will not cause relaxation of the cup and, therefore, loss of clamping strength. To assure uniform strain in the torsional mode, the cup must be 4 in. deep. That depth completely utilizes the 2-3/4-in. expanding portion of the arbor while allowing a minimum of 1-in. clearance between the bottom of the arbor and the bottom of the cup.

Titanium cups and disks for test specimens were to be supplied by AFML. Since titanium disks were not initially available, aluminum and stainless steel disks were used. Severe buckling of these disks was noted--the buckling

presumably being due to radially nonuniform heating. Recent runs with titanium disks machined by SRL to check buckling are encouraging. If buckling proves to be a problem, it may be necessary to modify the sample design and/or holding arrangement to assure reliable test data. Preliminary alternative designs have been prepared.

The hydraulic clamp extends through the top of the upper chamber via an O-ring seal. The clamp is turned at the top by a motor connected through a cam and torque arm (see Figs. 2, 3, and 4). This arrangement applies a torsional distortion to the sealant bead of the test specimen. The seal can be loaded in torsion from 0 to ± 0.030 in. on the circumference at a rate of 0 to 20 Hz. The strokes and cycles are independently variable through their entire ranges. The disk is driven up and down at its center by another motor connected via a bellows through the bottom of the lower chamber (see Fig. 4). The drive is capable of vertical motion from 0 to ± 0.030 in. at a rate of 0 to 20 Hz. The two drives are capable of continuous variability and are cycled and controlled independently.

The motor driver packages selected were high performance Electro-Craft Model 763 motors with the P-6200 control. These motor drivers were selected because of their very smooth performance at all speeds from 0 to 1800 rpm. Also, they can be set with high precision within the range 0 to 1200 rpm.

In the design of the dynamic sealant evaluation equipment, large safety factors were incorporated to minimize down time and recalibration requirements. As an example, calculations indicate that 107 oz-in. of torque was required to pull the disk down 0.050 in. against a 15-psi vacuum. Consequently, a motor having 620 oz-in. of torque for a 5.8 safety factor was selected. A second example is the roller bearings used as cams to drive the disk or cup. A load of 172 lb was the calculated load on the race. Bearings were selected that would accept a 920-lb side load on the race for a 5.3 safety factor.

The displacements in torque and joint opening are being measured using Schaevitz Model GCD-121-050 linear voltage displacement transducers (LVDT) having a repeatability of 0.000025 in., with a linearity of ± 0.25% of full range. The full range of this transducer is 0.100 in.; therefore, the

linearity is ± 0.00025 in. The joint opening transducer is spring loaded against the disk at the elastomeric joint, 1-1/2 in. from the center. The torsional displacement is being measured tangentially to the cup at the cup circumference, with the transducer being spring loaded on the driving cam arm. The displacements are shown on three Analogic Digital Panel Meters, Model AN2532--one each for disk vertical deflection, clamp vertical deflection, and clamp torsional deflection--and on a Brush Model 220 Strip Chart Recorder. Presently, the complete cycles are shown on the meters and on the recorder. A modification is planned whereby the peak value of the displacement will be detected and displayed; also the difference between the top and bottom deflection--which is the actual joint opening distortion--will be displayed.

Fuel is pumped from a storage tank during the evaluation run and into a dump tank after the test, by Masterflex Variable Speed Pumps (see Fig. 1).

Pressure in the chambers is controlled by a Mensor Quartz Manometer/Controller. This instrument will control the pressure over the range 0 to 32 in. Hg. The quality of the component parts and a calibration chart traceable to NBS classify the controller as a secondary standard. Pressure in the upper chamber is currently being maintained at 3-5 psi above that in the lower chamber by a Hoke 2403 Differential Regulator (see Fig. 5).

A leak detection system which shuts down the unit when fuel leaks through the joint to the region simulating the outside surface of the aircraft is to be supplied as GFE. Since this double set point leak detector is not yet available, leaks are presently being detected by pressure rise using a Fredericks Televac Model 2C-M1-Dual-CAB with PCR Controller. This unit is also used as a pressure gauge during preliminary evacuation and passivation.

The joint temperature, which is controllable from -100°F to +600°F, is measured by two iron-constantan thermocouples placed against the lower side of the disk directly under the sealant joint. One thermocouple is connected to a Honeywell Electronik 15 Recorder which also has a reference thermocouple at room temperature. The other thermocouple is connected to the Thermac Temperature Controller.

The heaters are Chromalox Tubular Heaters, triangulated, 3/8 in. Incoloy sheath, 240 V, 1350 W. Cooling is accomplished by means of 1) a closed-cycle water-cooling system, the water being pumped through cooling coils on the inside and outside of the chambers, and 2) another coil having small holes which is located above the specimen disk and connected to liquid nitrogen; this coil is isolated--except during the cooling cycle--by solenoid valves SV5 and SV6 to allow pressure different from atmospheric to be maintained inside the chamber. During the cooling cycle, this coil sprays cold nitrogen vapor and/or liquid nitrogen onto the disk.

Much of the instrumentation for the sealant evaluation system was salvaged from evaluation equipment supplied by the Air Force. A temperature controller, a recorder, and the programmer were readily adapted to the new system. However, some items were found to be defective and had to be replaced. Also, the consoles for mounting the instrumentation were bulky and inaccessible; therefore, standard rack mount cabinetry was used to assure ready access to all instruments (see Fig. 1).

SECTION III

PHASE II: EVALUATIONS

The dynamic evaluation machine has been set up in a laboratory of the Research Applications Division at SRL's Research Campus on Indian Ripple Road, Dayton, Ohio. SRL is in the process of installing an automatic Halon fire-protection system for that laboratory.

Evaluations are being conducted on several sealants selected by the AFML Project Engineer. The material which has been chosen for initial evaluation is Dow Corning 77-028 fluorosilicone. The sealants are being evaluated under a variety of conditions (e.g., vapor temperatures of 450, 500, and 550°F). The evaluations, utilizing several samples of the same Dow Corning material, are conducted under identical conditions. The goal is to provide sufficient information to permit correlation with more expensive flight test data in order that the more economical laboratory method may be used in evaluating presently available sealants and those now under development.

The test procedure for the initial evaluations is outlined below. First, the sealant to be evaluated is used to bond the disk to the cup (Fig. 6 is a photograph of such a bonded specimen). The upper chamber is then raised, the specimen inserted into the tester, and the thermocouple connected to the disk. The cup is then gripped by tightening the hydraulic clamp from outside the upper chamber at the top.

Before testing, the upper and lower chambers are purged with nitrogen by evacuating with Solenoid Valves SV1 and SV2 open (see Fig. 5) and then opening Solenoid Valve SV4 and the nitrogen regulator valve. After purging is complete, Valves SV1, SV2, and SV4 are closed and SV3 is opened. For the duration of the evaluation, both chambers are filled with nitrogen. The pressure in the lower chamber, which simulates the region outside a fuel tank, is preset at a level (e.g., 1/3 atmosphere) which simulates atmospheric pressure during an actual flight. The upper chamber--which corresponds to the interior of the fuel tank--is maintained by the differential regulator at a pressure which is 3-5 psi above that in the lower chamber and thus simulates a pressurized fuel tank.

At the beginning of the test cycle, fuel (e.g., JP-7) is pumped into the upper chamber. The test specimen is then heated to a temperature (e.g., 250°F) simulating that to which a tank containing liquid fuel might rise. Independently programmed tension and torsional deflections (e.g., 0.005 in. tension at 10 cycles/min. and 0.002 in. torsional at 2 cycles/min.) are applied simultaneously to the specimen. This portion of the cycle is continued for a specified time (e.g., 30 min.); then, the fuel is pumped out--except for a thin layer on the bottom of the upper chamber--and the temperature is elevated (e.g., to 550°F) to simulate flight with a largely vapor filled tank. The higher vapor temperature is held for another preset period (e.g., 90 min.). The application of mechanical strains continues during this time.

Afterward, the specimen is cooled by a combination of vapor from liquid nitrogen [Valves SV5 and SV6 (see Fig. 5) are opened during the cooling phase] and water to simulate the cooling which occurs during subsonic flight and landing. Mechanical strains are also applied during the cooling cycle.

If the sealed joint has not failed, the cycle is then repeated automatically for up to 24 hr. If, after 24 hr, the sample still has not failed, the program card is reset manually and the evaluation then continues automatically.

When the sealant fails, leakage of the fuel into the lower chamber is detected. The leak detector to be supplied by AFML will detect hydrocarbons via flame ionization. The detector presently being used detects the pressure difference generated in the lower chamber by the leaking fuel.

SECTION IV

RESULTS

One of the major results to date is the discovery that significant distortions occur due to heating of the sample disk. In tests with aluminum disks, the samples were found to be warped after the thermal cycle was completed (typically 1/4 to 1/2 in. after release from the chamber). Titanium disks (B120) did not buckle permanently, but readings on the joint opening sensor revealed that some approximately cyclic distortion was occurring. The distortion has been measured only at the point where the LVDT is located. One disk had only 2 mils thermal distortion, but a second had 15 mils under the same conditions. Discovery of the cyclic thermal distortions was possible because the displacements of the disk are directly measured in the dynamic evaluation machine. The distortion is due to nonuniform disk heating. The portion of the disk near the perimeter is not heated so strongly as the region nearer the center since the disk is in thermal contact with the chamber walls.

Many of the samples evaluated to date (Dow Corning 77-028, a fluorosilicone) failed quickly due to poor adhesion of the sealant to the cup and/or disk. The relative importance of thermal distortions and poor adhesion in these failures is not clear.

Mechanical motions were applied to the same type of samples with no heating. Cyclic torsional motions as large as ± 0.028 at the sample cup perimeter applied for several hours caused no breakage of the seals.

SECTION V

CONCLUSIONS

In order to provide an economical facility for dynamically evaluating elastomeric fuel tank sealants, a unique system has been developed which subjects the sealant material in the laboratory to mechanical forces, pressures, temperatures, and fuel-exposure conditions closely simulating those experienced in aircraft integral fuel tanks during flight. The system can simulate a complete flight profile including fuel loading, take-off, cruise and high-speed flight, landing, and shutdown. The system is capable of repeating these simulated flight conditions with a high degree of accuracy. The equipment allows automatic evaluation of elastomeric sealants of the continuous fillet, corner, and channel (groove injection) configurations.

Initial evaluations with Dow Corning 77-028 fluorosilicone sealants have demonstrated that large mechanical distortions alone over periods of several hours do not cause sealant failure. Thermal distortion of the sample which occurs during the heating may be important; this fact must be evaluated.

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